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Contractor Report ARAED-CR-90009

**ADIABATIC COMPRESSION INITIATION CHARACTERISTICS OF LIQUID  
PROPELLANT NITROMETHANE UNDER DYNAMIC FILL CONDITIONS**

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ARDEC  
Project Engineering

August 1990

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| <p>SwRI used Princeton Combustion Research Laboratories (PCRL) to perform the designated tasks. Based upon their results of their limited laboratory-scale experiments in the field engineering assessments and preliminary findings from TEXS system modeling, PCRL concluded that the use of nitromethane in Tactical Explosive System is probably safe. PCRL has also advised that any hazards that may exist can be minimized by taking the following recommendations:</p> <ol style="list-style-type: none"><li>1. Change off-loading nozzle valve to the type that shuts more slowly.</li><li>2. Make sure that the 1.5 in. connecting pipe is PE (expandable) and not steel or other heavy walled pipe.</li><li>3. Make sure that all valves in the 1.5 in. are wide open types and not constructed of steel.</li></ol> |       |   |   |  |                                   |
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## INTRODUCTION

Southwest Research Institute (SwRI) was contracted under DOD Contract DAAA21-88-R-0021, Delivery Order 0003 to perform the following tasks:

1. Provide data on physical properties of nitromethane that are important in characterizing hydrodynamic surge pressure during dynamic fill processes and in characterizing bubbler collapse processes. Such data includes kinematic viscosity, vapor pressure, gas solubility (N<sub>2</sub>, air), and compressibility. These physical properties are desired at cold and hot temperature extremes (-25°F to 126°F).
2. Conduct theoretical analysis of adiabatic compression phenomenon of bubbles in liquid nitromethane associated with hydrodynamic surge pressure wave in nominal dynamic fill operations by utilizing available experimental data and empirical correlations.
3. Conduct limited essential lab-scale experiments with government-furnished material (GFM) nitromethane sample for confirmation of Item 2 above.
4. Provide preliminary hazards statement based on results of Items 1, 2, and 3 available. This preliminary hazards statement will be refined at the conclusion of the program effort.
5. Define "Phase II" Program Plan to establish safe operating corridor in multiparameter space for dynamic fill process of nitromethane, to account for a typical or pathological performance. This must take into account "what if" scenarios to properly answer personnel safety concerns.

## TASKS PERFORMED

With the concurrence of U.S. Army Armament, Munition and Chemical Command, Picatinny Arsenal, New Jersey, SwRI used Princeton Combustion Research Laboratories (PCRL) to perform the designated tasks. PCRL has key technical personnel, equipment and facilities that were essential to the proposed study. During the past several years, PCRL has conducted experimental investigations on the sensitivity of liquid propellants to compression ignition. This phenomenon has been identified as one of the potential sources of secondary ignition hazard as relates to the TEXS environment. Here we define secondary ignition as any ignition due to sources other than the desired direct initiation. In particular, compression ignition is that secondary ignition arising from hot spot development associated with bubble collapse under compressive loading of the liquid nitromethane charge associated with hydrodynamic surge pressure waves. These bubbles may be brought into the TEXS pipeline from fill lines during the prefiring nitromethane dynamic filling process or may be formed by cavitation during the filling process.

The extent to which real fluid effects moderate the bubble dynamics needs to be quantified, especially at temperature extremes. Bubbles in the liquid nitromethane charge may contain reactive vapor or a mixture of permanent gas and vapor.

PCRL has the equipment and instrumentation necessary to characterize the kinematic viscosity, vapor pressure, gas solubility ( $\text{N}_2$ , air), and compressibility of nitromethane at cold and hot temperature extremes. In those instances where the desired data are available in the literature [government-furnished material (GFM) compendium of nitromethane data], these data will be used to supplement the PCRL-generated data. PCRL has generated such data in the past on hydroxyl ammonium nitrate (HAN)-based liquid monopropellants.

PCRL conducted limited essential laboratory-scale experiments with GFM-furnished nitromethane for confirming the response to nitromethane to the hydrodynamic surge pressure wave in nominal dynamic fill operations in TEXS application. A specialized dynamic flow fixture is operational at PCRL for obtaining flow characteristics (volumetric flow rates, water-hammer hydraulic effects, etc.) at various conditioning temperatures in the range  $-25^\circ\text{F}$  to  $126^\circ\text{F}$ . A transparent chamber permits high-speed cinematography of the dynamic flow tests.

PCRL attended program briefing meetings held in Monroe, Louisiana, Yuma, Arizona, and Dover, New Jersey, and gave a presentation (Appendix A) in fulfillment of the contractual tasks.

## CONCLUSIONS

Based upon the results of their limited laboratory-scale experiments, PCRL concluded that the use of nitromethane in TEXS is probably safe. PCRL has also advised that any hazards that may exist can be minimized by taking the following recommendations:

- 1) Change off-loading nozzle valve to the type that shuts more slowly.
- 2) Make sure that the 1.5-in. connecting pipe is PE (expandable) and not steel or other heavy walled pipe.
- 3) Make sure that all valves in the 1.5-in. pipe are wide open types and not constructed of steel.

APPENDIX A  
PRESENTATION BY  
PRINCETON COMBUSTION RESEARCH LABORATORIES

# **INVESTIGATION OF NM SAFETY FOR TEXS SYSTEM<sup>+</sup>**

**DR. NEALE A. MESSINA, DR. MARTIN SUMMERFIELD  
& DR. MAREK TARCZYNSKI**

**PRINCETON COMBUSTION RESEARCH LABORATORIES, INC.  
MONMOUTH JUNCTION, NJ**

**25 JULY 1989**

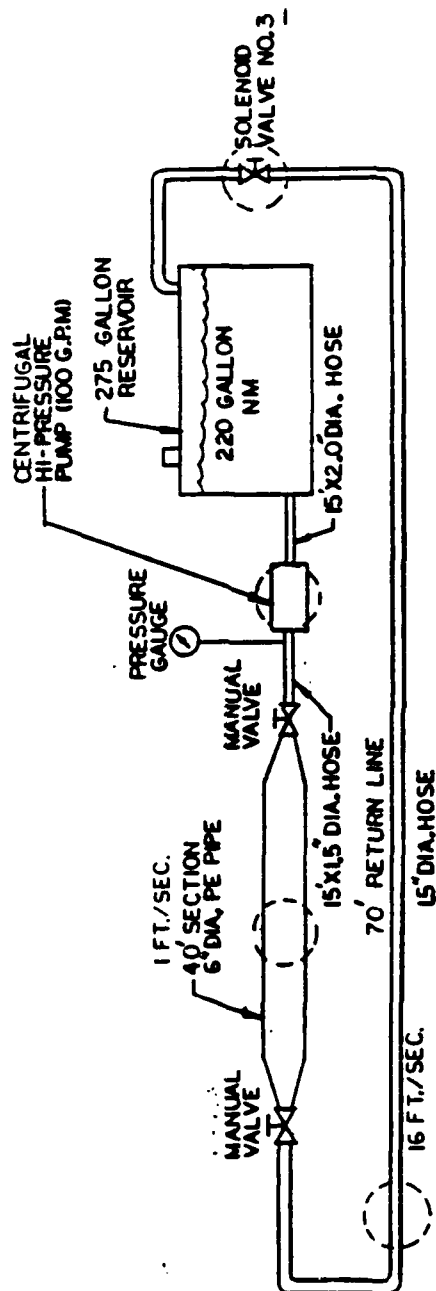
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**<sup>+</sup> CONDUCTED ON P.O. 65620 ON PRIME CONTRACT  
DAAA21-88-D-0021; MR. WILLIAM SEALS, COTR,  
U.S. ARMY ARDEC, PICATINNY ARSENAL, NJ**

## **OBJECTIVES OF PCRL WORK (BASED ON CONTRACT SOW)**

- 1. PROVIDE DATA ON PHYSICAL PROPERTIES OF NM THAT ARE IMPORTANT IN CHARACTERIZING HYDRODYNAMIC SURGE PRESSURE DURING DYNAMIC FILL PROCESS AND IN CHARACTERIZING BUBBLE COLLAPSE PROCESS.**
- 2. CONDUCT THEORETICAL ANALYSIS OF ADIABATIC COMPRESSION PHENOMENON OF BUBBLES IN LIQUID NM -- BY UTILIZING AVAILABLE EXPERIMENTAL DATA AND EMPIRICAL CORRELATIONS.**
- 3. CONDUCT LIMITED ESSENTIAL LAB-SCALE EXPERIMENTS FOR CONFIRMATION OF ITEM 2 ABOVE.**
- 4. PROVIDE HAZARDS JUDGMENTS RELEVANT TO TEXS SYSTEM, TEXS TEST SET-UP, AND LOADING/OFF-LOADING OF BOTH, AS REGARDS ADIABATIC COMPRESSION HAZARD.**
- 5. DEFINE "PHASE II" PROGRAM PLAN TO ESTABLISH SAFE OPERATING CORRIDOR FOR DYNAMIC FILL PROCESS OF NM RELEVANT TO TEXS SYSTEM AND TEXS TEST SET-UP.**

TEXS  
HYDRAULIC HAMMER TEST SET-UP  
(YUMA, ARIZONA)



SOLENOID VALVE NO. 3 (TESTED)

1. PLUG VALVE
2. DIAPHRAGM VALVE
3. BALL VALVE

○ INDICATES  
RISK ZONES

6" PIPE

MATERIAL: PE

O.D. = 6.625"

I.D. = 6.115"

15' HOSE (300EPDM)

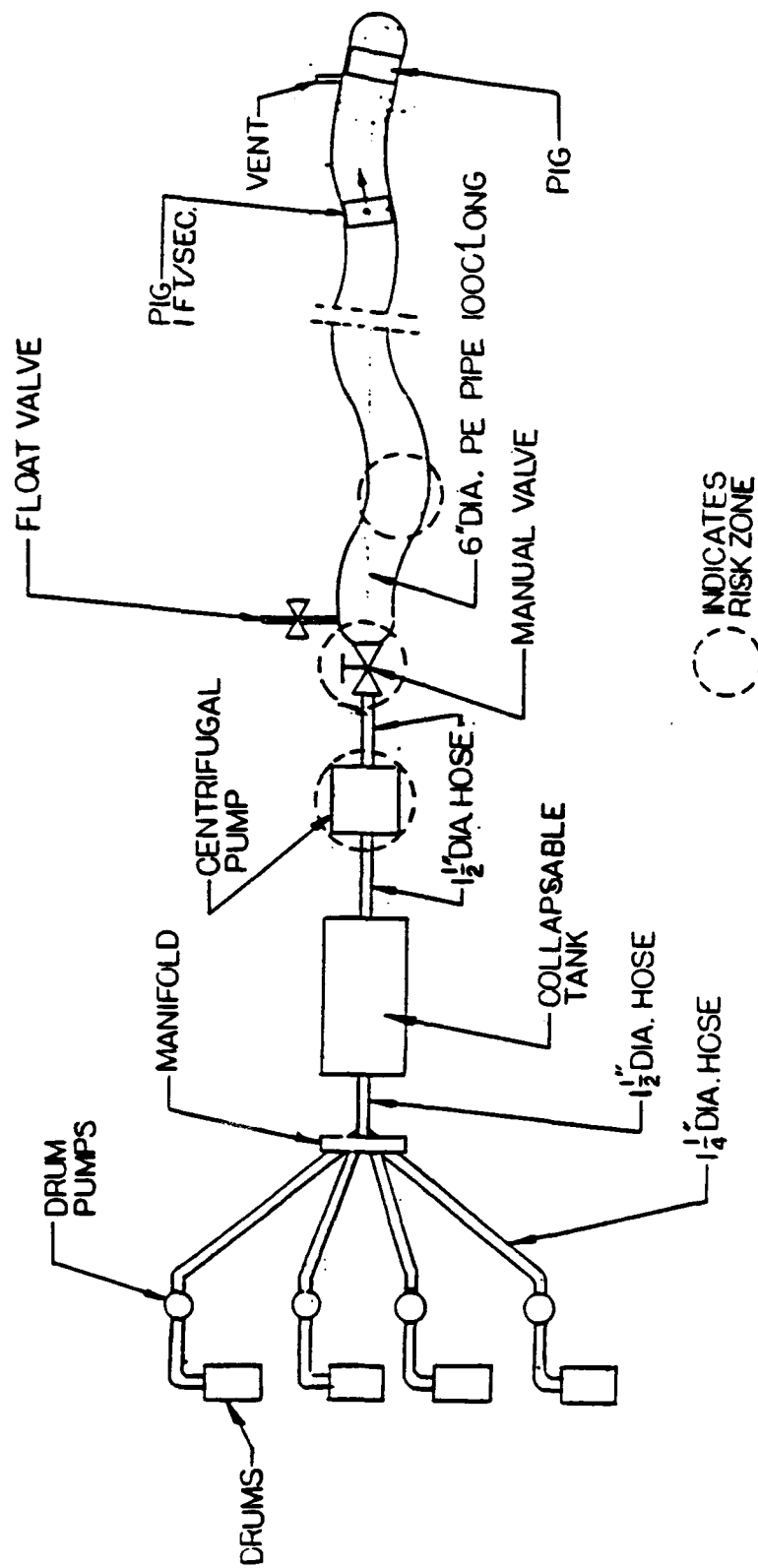
MATERIAL: NYLON & EPDM LINING

I.D. = 1.5 (THK. 0.1)

CONTAMINANTS

SAND, SOAP, RUST, WATER,  
AMINES NOT CONSIDERED

## IEXS SYSTEM



## **SOURCES OF INFORMATION AVAILABLE TO PCRL:**

- 1. INFORMATION FROM OFFICE OF MINES, COUNTERMINES, DEMOLITIONS (PM-MCD) OF PICATINNY ARSENAL.**
- 2. GENERAL LITERATURE -- JOURNAL ARTICLES, HANDBOOKS, ETC.**
- 3. LITERATURE AND SUMMARIES COMPILED BY HERSHKOWITZ FOR PM-MCD.**
- 4. TEXS-NM SYSTEM HANDBOOK PREPARED BY ANGUS -- INCLUDING BROCHURE ON NM.**
- 5. TEXS SYSTEM DESCRIPTION PROVIDED BY PM-MCD.**

**(CONTINUED)**

## **SOURCES OF INFORMATION AVAILABLE TO PCRL: (CONT'D)**

### **6. PCRL EXPERIMENTS AND INTERPRETATIONS:**

- A) COMPRESSION-IGNITION TESTS WITH DISPERSED ULLAGE  
(FINE BUBBLES) AND WITH NON-DISPERSED POCKET OF AIR**
- B) U-TUBE TESTS (NATO SPECIFICATION PROCEDURE) WITH  
COLLECTED ULLAGE.**

### **7. MATH MODELING AT PCRL:**

- A) HYDRAULIC-HAMMER PRESSURE RISE FOR VARIOUS POSSIBLE  
CONDITIONS IN TEXS**
- B) DYNAMICS OF CAVITY COLLAPSE -- VARIOUS POSSIBILITIES.**

### **8. ANGUS PRESENTATIONS AT MONROE, AND ALSO HANDOUT BOOK, 20 JUNE 1989.**

### **9. VISIT TO YUMA PROVING GROUND, OBSERVATIONS OF ACTUAL SYSTEM.**

## **RISK ZONES OF TEXS-ANGUS NM SYSTEM CONSIDERED BY PCRL FOR SAFETY:**

- 1. SUDDEN CLOSURE OF VALVES -- VARIOUS LOCATIONS -- AND RESULTING HYDRAULIC-HAMMER PRESSURES -- FOR VARIOUS ASSUMED CLOSING TIMES, IN MSEC.**
- 2. EFFECT ON NEAT NM (A) WITHOUT BUBBLES AND (B) WITH SMALL VAPOR BUBBLES DUE TO CAVITATION OF NEAT NM -- SUDDEN PRESSURES FROM 1.**
- 3. EFFECT ON NM COLUMN WHEN AIR IS PRESENT, EITHER IN FORM OF FINE BUBBLES OR IN COLLECTED POCKETS OF 5-10 CM SIZE.**
- 4. HYDRAULIC-HAMMER DUE TO "RAPID" STOPPAGE OF PIG AT (A) ONE END AT FINISH OF FILLING AND (B) SOMEWHERE IN 6-IN DUCT -- DEFORMATION OF DUCT: CONSIDERATION ESPECIALLY OF VARIOUS STOP TIMES -- IN MSEC.**
- 5. HYDRAULIC-HAMMER (MUCH LARGER BUT SHORTER TIME) IN 1.5-IN CONNECTING DUCT -- VARIOUS STOP TIMES, IN MSEC.**

**(CONTINUED)**

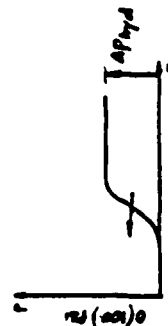
**RISK ZONES OF TEXS-ANGUS NM SYSTEM CONSIDERED BY  
PCRL FOR SAFETY: (CONT'D)**

- 6. QUESTION OF DETONATION OF NM IN EITHER DUCT WHEN INITIATED  
PERHAPS BY EXPLOSION OF NM NEAR AIR POCKET (MUCH WEAKER THAN  
C-4 DONOR EXPL.)**
- 7. PROCEDURE OF OFF-LOADING, ESPECIALLY SNAP-SHUT VALVE IN  
OFF-NOZZLE.**
- 8. PUMPING HAZARD: QUESTION OF CAVITATION (FINE VAPOR BUBBLES) IN  
(A) AIR PUMPS AND (B) TRANSFER PUMP.**
- 9. AIR POCKETS IN PUMP HOUSINGS (STEEL); RAPID COMPRESSION.**
- 10. EXPLOSION OF NEAR-EMPTY DRUM -- LATEST INFORMATION FROM  
PM-MCD ABOUT EXPLOSION OF NEAR-EMPTY DRUM AT GERMAN  
PLANT OF DYNAMIT NOBEL CO. IN MAY 1989.**

# EXPERIMENTAL STUDY OF HYDRAULIC HAMMER EFFECTS:

## TEXS

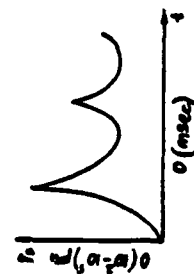
SUDDEN STOP OF THE  
FLOW DUE TO PIG STOP  
OR VALVE CLOSURE



HYDRAULIC PRESSURE  
WAVE TRAVELS THROUGH  
BUBBLY LIQUID

COMPRESSION PRESSURE IS  
APPLIED TO BUBBLY LIQUID

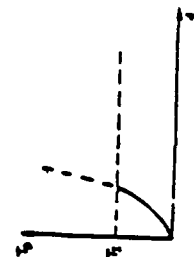
COMPRESSION OF AIR BUBBLE  
DUE TO PUSH PRESSURE  
APPLIED TO LIQUID COLUMN,  
WHICH ACCELERATES LIQUID.



VIOLENT BUBBLE AND  
AIR POCKET COLLAPSE  
RESULT IN VERY HIGH  
BUBBLE PRESSURE AND  
TEMPERATURE

VIOLENT AIR AND/OR VAPOR  
BUBBLE COLLAPSE RESULTS  
IN VERY HIGH BUBBLE  
PRESSURE AND TEMPERATURE

AIR POCKET AT THE END OF  
U-TUBE IS COMPRESSED BY  
MOVING LIQUID, ANALOGOUS  
TO DYNAMIC BUBBLE COLLAPSE



TEMPERATURE RISE OF  
LIQUID SURROUNDING A  
BUBBLE MAY RESULT IN A  
RUNAWAY REACTION IN A  
LIQUID (MODIFIED BY  
HEAT LOSS)

TEMPERATURE RISE OF  
LIQUID SURROUNDING A  
BUBBLE MAY RESULT IN A  
RUNAWAY REACTION IN A  
LIQUID (MODIFIED BY  
HEAT LOSS)

TEMPERATURE RISE OF  
LIQUID SURROUNDING A  
BUBBLE OR POCKET MAY  
RESULT IN RUNAWAY  
REACTION IN A LIQUID  
(MODIFIED BY HEAT LOSS)

## PCRL COMPRESSION TESTER

- (1) SUDDEN STOP OF THE  
FLOW WITH APPLIED  
(DRIVING) PRESSURE
- (2) APPLICATION OF PRESSURE  
FROM EXPLOSIVE CHARGE  
TO PRE-FILLED CHAMBER

NOT APPLICABLE

## PCRL U-TUBE TESTER

# **CONDITIONS INVESTIGATED EXPERIMENTALLY BY PCRL**

1. LIQUID NON-BUBBLY NM (NEAT) ..... PCRL COMPRESSION TESTER
2. LIQUID NM WITH FINE CAVITATION BUBBLES ..... PCRL COMPRESSION TESTER
3. LIQUID NM WITH FINE AIR BUBBLES .....
 

{
 

(A) PCRL COMPRESSION TESTER  
(3%, 10% ULLAGE)  
(B) PCRL U-TUBE TESTER (FLAT  
END-PRESSURE TRANSDUCER)
4. LIQUID NM WITH LARGE AIR POCKETS ..... PCRL U-TUBE TESTER  
(CONCAVE CUP END)

# **RESULTS OF CALCULATIONS FOR 6-IN DIAMETER TUBE (FLOW RATE 100 GPM OR 1 FPS)**

| MATERIAL | AMPLITUDE OF<br>HYDRAULIC HAMMER |   | PRESSURE<br>RISE TIME<br>(MS) | AIR CAVITY<br>DIAMETER<br>(MM) | MAX CAVITY<br>PRESSURE<br>(PSI) |
|----------|----------------------------------|---|-------------------------------|--------------------------------|---------------------------------|
|          | PRESSURE WAVE<br>(PSI)           |   |                               |                                |                                 |
| PE       | 10                               | 0 | (INSTANTANEOUS)               | 20                             | 41                              |
|          |                                  |   |                               |                                |                                 |
| RIGID    | 74                               | 0 | (INSTANTANEOUS)               | 20                             | 800                             |
|          |                                  | 1 |                               |                                |                                 |
|          |                                  |   |                               | 20                             | 400                             |

# **RESULTS OF CALCULATIONS FOR 1.5-IN DIAMETER HOSE (FLOW RATE 100 GPM OR 16.8 FPS)**

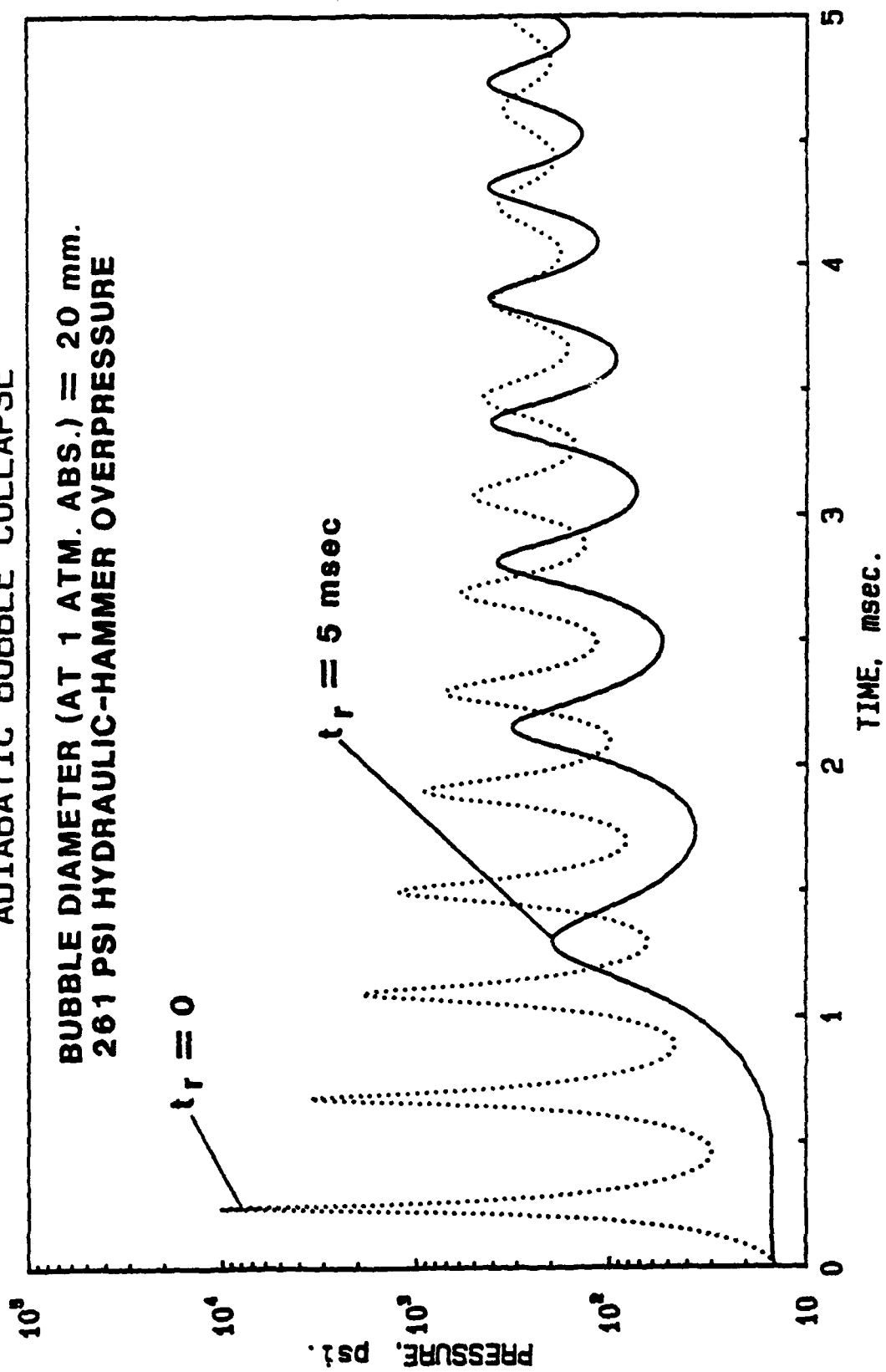
| <b>MATERIAL</b> | <b>AMPLITUDE OF<br/>HYDRAULIC HAMMER<br/>WAVE PRESSURE<br/>(PSI)</b> | <b>PRESSURE<br/>RISE TIME<br/>(MS)</b> | <b>BUBBLE<br/>DIAMETER<br/>(MM)</b> | <b>MAX. BUBBLE<br/>PRESSURE<br/>(PSI)</b> |
|-----------------|--|--|-------------------------------------|---|
| <b>PE</b>       | <b>261</b>   | <b>0</b>                               | <b>20</b>                           | <b>10,369<sup>1</sup></b>                 |
|                 |  | <b>1</b>                               | <b>20</b>                           | <b>1,294</b>                              |
|                 |  | <b>5</b>                               | <b>20</b>                           | <b>198<sup>1</sup></b>                    |
|                 |  | <b>25</b>                              | <b>20</b>                           | <b>30</b>                                 |
| <b>STEEL</b>    | <b>800</b>   | <b>0</b>                               | <b>20</b>                           | <b>122,400</b>                            |
|                 |  | <b>1</b>                               | <b>20</b>                           | <b>4,930</b>                              |
|                 |  | <b>1</b>                               | <b>2</b>                            | <b>143</b>                                |
|                 |  | <b>5</b>                               | <b>20</b>                           | <b>369</b>                                |
|                 |  | <b>25</b>                              | <b>20</b>                           | <b>91</b>                                 |
| <b>RIGID</b>    | <b>1247</b>  | <b>0.1</b>                             | <b>20</b>                           | <b>96,000</b>                             |
|                 |  | <b>1</b>                               | <b>20</b>                           | <b>8,205</b>                              |
|                 |  | <b>1</b>                               | <b>2</b>                            | <b>178</b>                                |
|                 |  | <b>5</b>                               | <b>20</b>                           | <b>548</b>                                |
|                 |  | <b>25</b>                              | <b>20</b>                           | <b>109</b>                                |

---

**1 VIEWGRAPH EXAMPLE**

# ADIABATIC BUBBLE COLLAPSE

BUBBLE DIAMETER (AT 1 ATM. ABS.) = 20 mm.  
261 PSI HYDRAULIC-HAMMER OVERPRESSURE



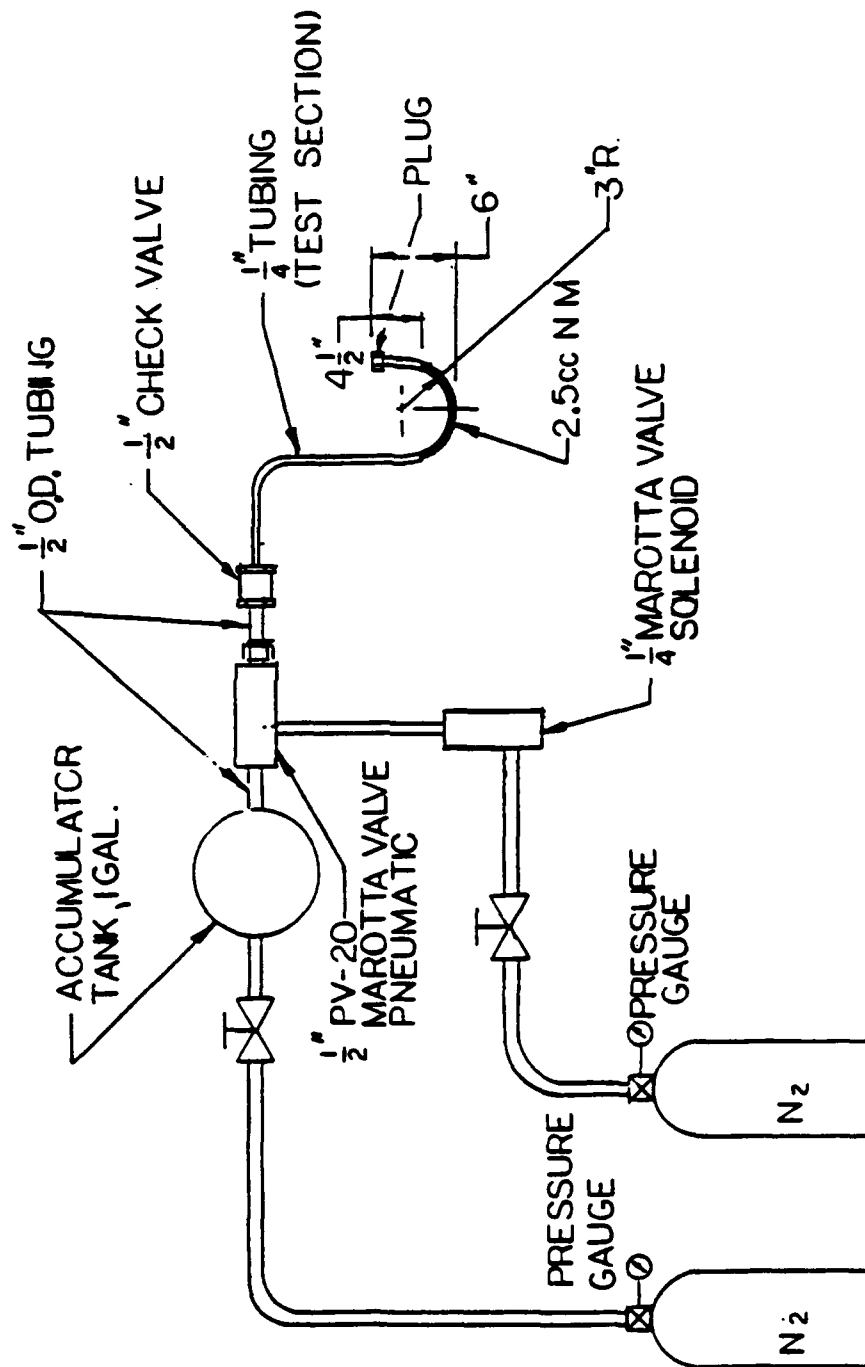
[illegible]

# **EXPERIMENTS IN PCRL COMPRESSION TESTER**

| CASE NO. | AIR ULLAGE CONTAINED      | HYDRAULIC OVERPRESSURE (PSI) | NUMBER OF TESTS AT  |       |       | RESULT  |
|----------|---------------------------|------------------------------|---------------------|-------|-------|---------|
|          |                           |                              | 20° C               | 55° C | 63° C |         |
| I        | NEAT                      | 1200 - 1300                  | 4                   | --    | --    | B (ALL) |
| II       | 3.1% MICRO-BUBBLE         | 1300                         | 3                   | --    | --    | B (ALL) |
|          | 10.0% MICRO-BUBBLE        | 1050-1340                    | 2                   | 3     | --    | B (ALL) |
|          |                           | 25000 <sup>1,2</sup>         | 1 (N <sub>2</sub> ) | 1     | --    | B (ALL) |
| III      | NM WITH 3.1% MACRO-BUBBLE | 1200-1250                    | 6                   | --    | --    | B (ALL) |
|          | 10.0% MACRO-BUBBLE        | 1265-1400                    | 6                   | 1     | 1     | B (ALL) |
|          |                           | 25000 <sup>1</sup>           | 1                   | --    | --    | B (ALL) |
|          |                           |                              | 2 (N <sub>2</sub> ) | --    | --    | B (ALL) |
| IV       | 18.0% MACRO-BUBBLE        | 2500                         | --                  | 1     | --    | B (ALL) |
|          | > 90% ULLAGE              | 800                          | 1                   | --    | --    | B (ALL) |
|          |                           | 2000                         | --                  | 2     | --    | B (ALL) |

- 
- 1 VERY FAST RATE OF PRESSURIZATION -- 25 KPSI/MSEC  
 BY IGNITION STARTER CHARGE
- 2 PRE-PRESSURIZED TO 400 PSI

# PCRL U-TUBE TESTER



# EXPERIMENTS IN PCRL U-TUBE TESTER (1/4-IN TUBE)

| PUSH<br>PRESSURE<br>(PSI) | MATERIAL | END-FITTING |  | PRESSURE<br>TRANSDUCER | MAX CAVITY<br>PRESSURE<br>(PSI) | RESULT |
|---------------------------|----------|-------------|--|------------------------|---------------------------------|--------|
|                           |          | CUP         |  |                        |                                 |        |
| 200                       | NM-ANGUS | CUP         |  | --                     | N/M                             | B      |
|                           | NM-ANGUS | CUP         |  | --                     | N/M                             | B      |
| 300                       | NM-ANGUS | --          |  | PT                     | 5500                            | B      |
|                           | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
|                           | NM-ANGUS | CUP         |  | --                     | N/M                             | B      |
|                           | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
| 500                       | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
| 600                       | NM-ANGUS | --          |  | PT                     | 8200                            | B      |
|                           | NM-ANGUS | --          |  | PT                     | 9420                            | B      |
|                           | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
|                           | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
| 1250                      | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
| 1300                      | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
| 1400                      | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
|                           | NM-ANGUS | CUP         |  | --                     | N/M                             | EXPL.  |
|                           | NM-99+%  | CUP         |  | --                     | N/M                             | EXPL.  |
|                           | NM-99+%  | CUP         |  | --                     | N/M                             | EXPL.  |
| 1350                      | NM-ANGUS | --          |  | PT                     | 15,000                          | B      |

(CONTINUED)

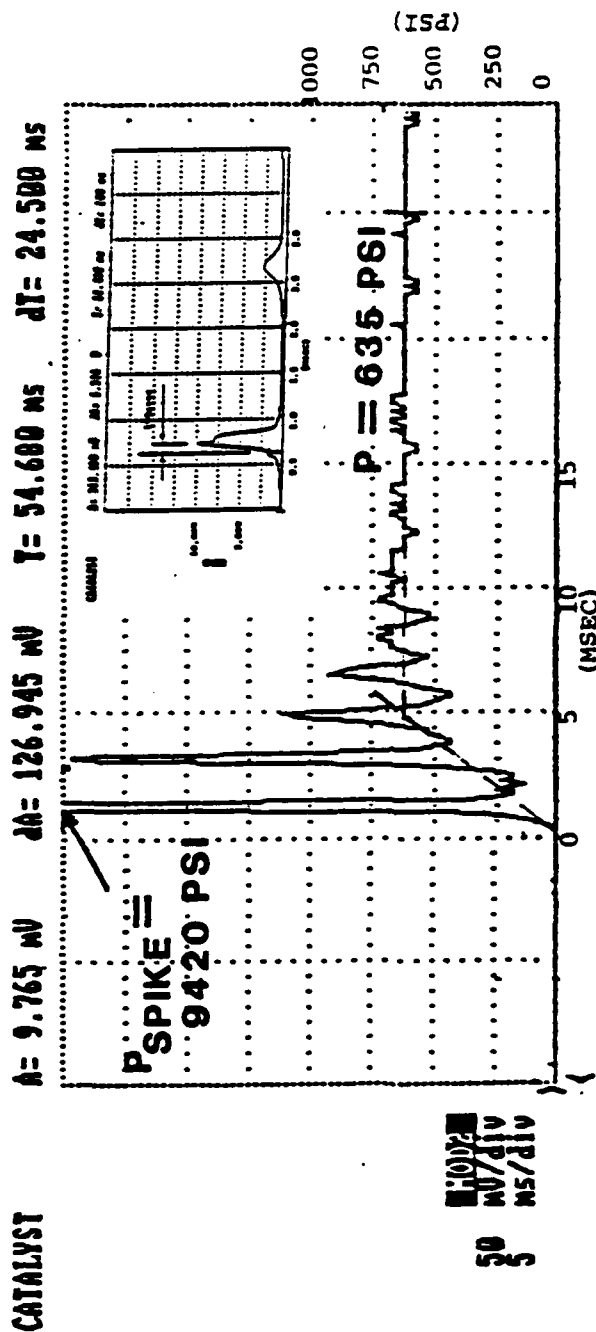
# EXPERIMENTS IN PCRL U-TUBE TESTER (1/4-IN TUBE) (CONT'D)

| PUSH<br>PRESSURE<br>(PSI) | END-FITTING |     | PRESSURE<br>TRANSDUCER | MAX CAVITY<br>PRESSURE<br>(PSI) | RESULT |
|---------------------------|-------------|-----|------------------------|---------------------------------|--------|
|                           | MATERIAL    | CUP |                        |                                 |        |
| 300                       | NM-ANGUS    | --  | PT                     | 5,500                           | B      |
| 600                       | NM-ANGUS    | --  | PT                     | 8,200                           | B      |
|                           | NM-ANGUS    | --  | PT                     | 9,420                           | B      |
|                           | WATER       | --  | PT                     | 7,900                           | B      |
| 800                       | NM-ANGUS    | --  | PT                     | 11,000                          | B      |
| 1,000                     | NM-ANGUS    | --  | PT                     | 11,600                          | B      |
| 1,200                     | NM-ANGUS    | --  | PT                     | 11,300                          | B      |
| 1,350                     | NM-ANGUS    | --  | PT                     | 15,000                          | B      |

(CONTINUED)

# U-TUBE TEST

2.5 CC NM-ANGUS      PUSH PRESSURE ~ 600 PSI



FILE:TEXCOMP.T003      ANGUS NM2.5CC U-TUBE TEST, PUSH PRESSURE 600PSI 22C P05KPSI

$$\frac{DP}{DT} \Big|_{\text{SPIKE}} = 80.0 \times 10^6 \frac{\text{PSI}}{\text{SEC}}$$

$$\frac{DP}{DT} \Big|_{\text{CONV}} = 0.15 \times 10^6 \frac{\text{PSI}}{\text{SEC}}$$

VALVE OPENING TIME ≈ 7 msec.

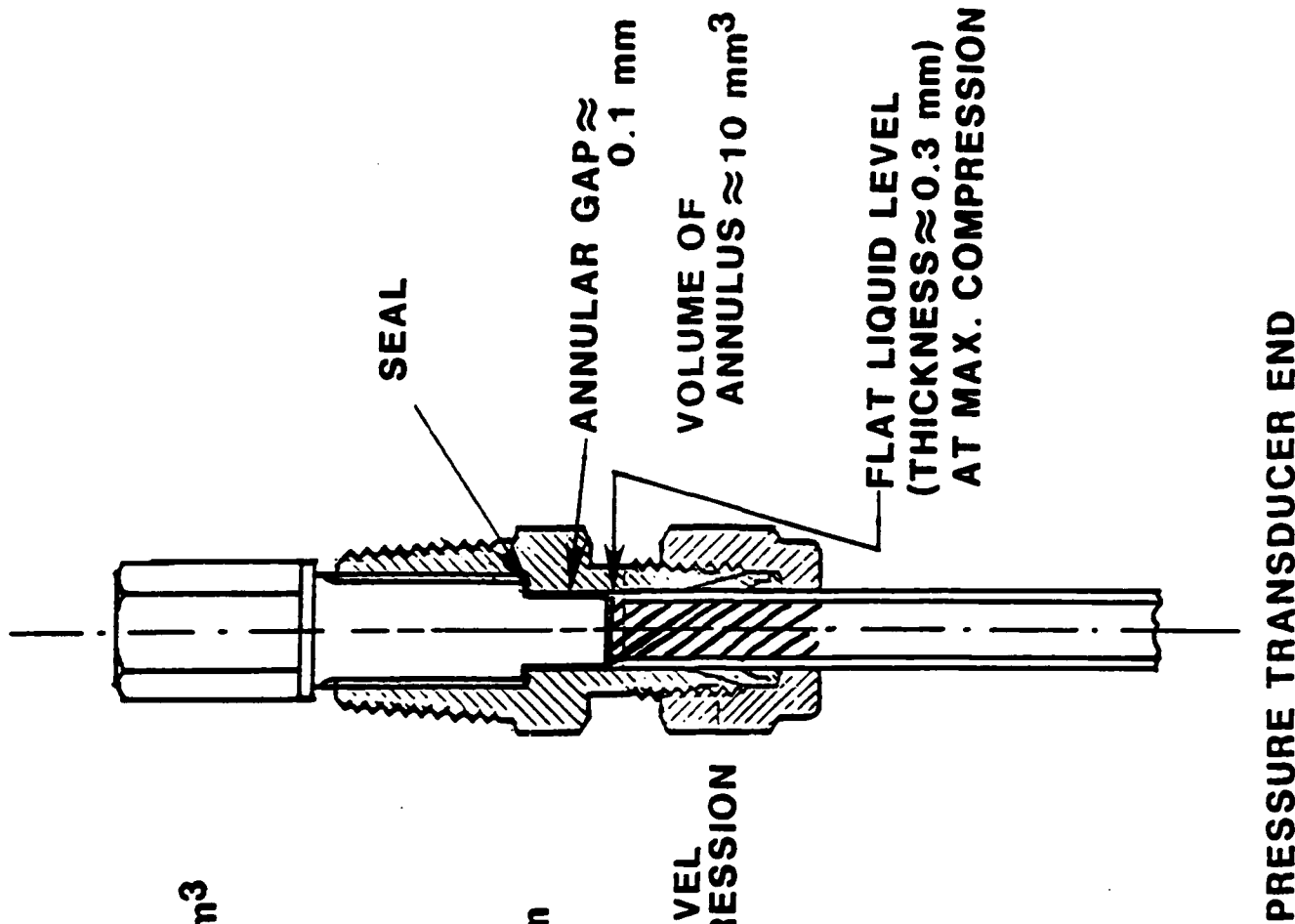
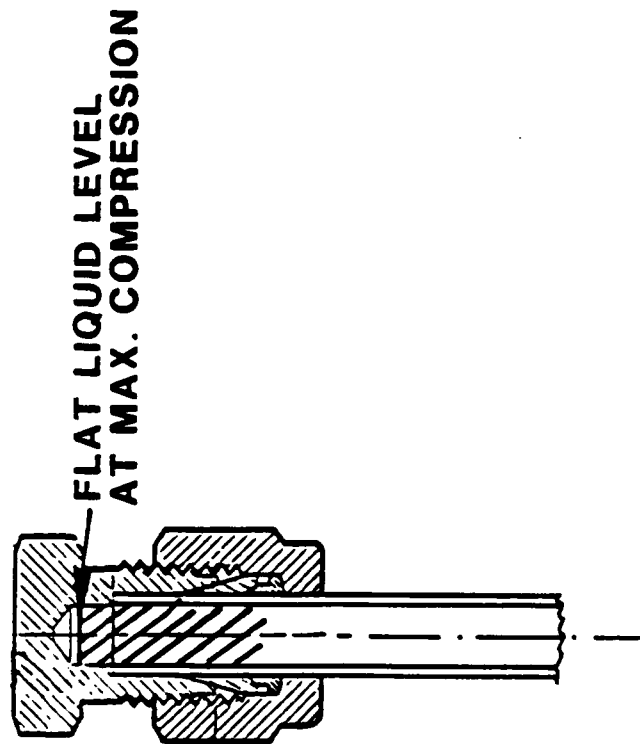
TYPICAL CAVITY VOLUME WHEN  
COMPRESSED TO 15,000 PSI IS 15 mm<sup>3</sup>

$$\tau_{\text{COOL}} \approx \frac{d^2 \text{ CAVITY}}{\alpha \text{ COMPRESSED AIR}}$$

$\propto$  COMPRESSED AIR

$\approx$  500 MSEC at  $d = 0.5 \text{ mm}$

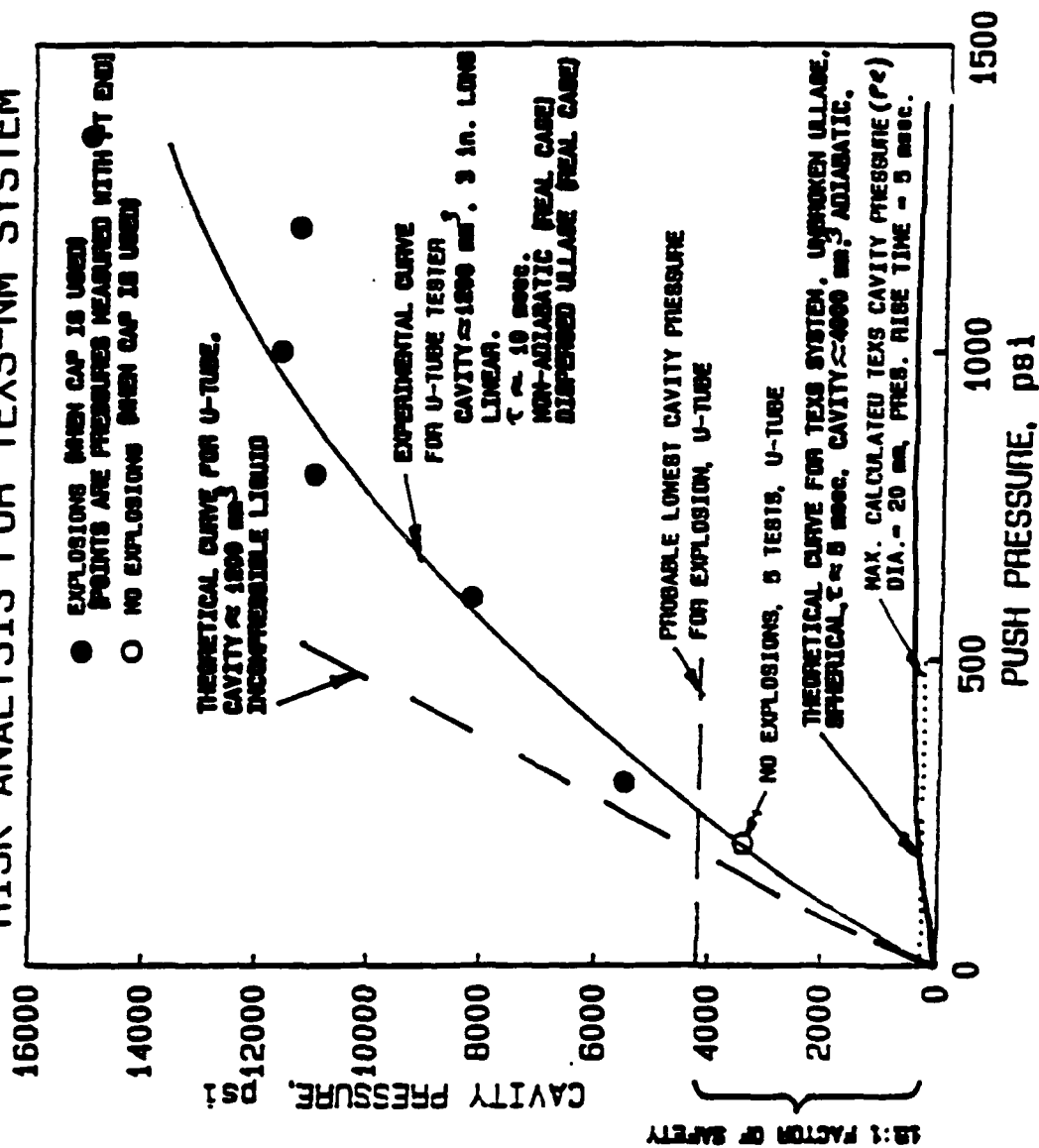
$\approx$  5 MSEC at  $d = 0.05 \text{ mm}$



# EXPERIMENTS IN PCRL U-TUBE TESTER (1/4-IN TUBE) HIGH TEMPERATURE (70°C) TESTS (CONT'D)

| PUSH<br>PRESSURE<br>(PSI) | MATERIAL | END-FITTING |    | PRESSURE<br>TRANSDUCER | MAX CAVITY<br>PRESSURE<br>(PSI) | RESULT |
|---------------------------|----------|-------------|----|------------------------|---------------------------------|--------|
|                           |          | CUP         |    |                        |                                 |        |
| 200                       | NM-ANGUS | CUP         | -- |                        | N/M                             | B      |
|                           | NM-ANGUS | CUP         | -- |                        | N/M                             | B      |
| 300                       | NM-ANGUS | CUP         | -- |                        | N/M                             | B      |
|                           | NM-ANGUS | CUP         | -- |                        | N/M                             | B      |

# RISK ANALYSIS FOR TEXS-NM SYSTEM



**PCRL'S ADVICE TO THE OFFICE OF MINES, COUNTERMINES, AND  
DEMOLITIONS OF PICATINNY ARSENAL**

- 1. SYSTEM IS PROBABLY SAFE -- HIGH PROBABILITY OF SAFETY --  
SMALL HAZARD.**
- 2. HAZARD CAN BE FURTHER MINIMIZED BY:**
  - (A) CHANGE OFF-LOADING NOZZLE VALVE TO TYPE THAT SHUTS MORE  
SLOWLY.**
  - (B) MAKE SURE THAT 1.5-IN CONNECTING PIPE IS PE (EXPANDABLE) AND  
NOT STEEL OR HEAVY-WALLED PIPE. WALL THICKNESS OF 0.2-IN OK.**
  - (C) MAKE SURE THAT ALL VALVES IN THE 1.5-IN PIPE ARE WIDE-OPEN TYPES  
(NOT GLOBE OR NEEDLE TYPES) AND PREFERABLY NOT STEEL.**

## **RECOMMENDED INVESTIGATIONS TBD IN ORDER TO MAKE MORE SURE OF SAFETY:**

- 1. CONDUCT TESTS TO SEE WHETHER 1.5-IN OR 6-IN DUCTS OF PE CAN DETONATE WHEN "HIT" BY AN EXPLOSION OF NM-AIR POCKETS. EXPERIMENTS INDICATE NO DETONATION, BUT THESE ARE IN 0.5-IN MAXIMUM DUCTS ONLY. DATA FROM JAMES AND HERSHKOWITZ LITERATURE SURVEY APPLY ONLY TO CASES WHERE DUCTS OF NM HAVE BEEN "HIT" BY DONOR EXPLOSIVES. CRITICAL DIAMETER AT 25°C REPORTED TO BE 1/2 INCH.**
- 2. MEASURE ACTUAL WATER-HAMMER PRESSURES IN GEOMETRIES SIMILAR TO ANGUS DESIGNED TEXTS SYSTEM, IN ORDER TO CHECK COMPUTATIONS OF PCRL; USE FAST-ACTING PIEZO-TYPE GAUGES TO LOOK FOR "SPIKE" OVERPRESSURES IN WATER-HAMMER WAVES (WHICH HAVE NOT BEEN MODELED).**

**(CONTINUED)**

## **RECOMMENDED INVESTIGATIONS TBD IN ORDER TO MAKE MORE SURE OF SAFETY: (CONT'D)**

### **3. FURTHER MATH MODELING:**

- (A) ANALYZE PEAK ULLAGE PRESSURES FOR OTHER SHAPES OF CAVITIES, TO AUGMENT CURRENT PCRL RESULTS ON COLUMN-TYPE AND SPHERICAL CAVITIES, AND INCLUDE THE EFFECTS OF HEAT CONDUCTION TO EITHER METAL OR PE CONTAINMENT.**
- (B) ANALYZE THE EFFECTS OF HIGH TEMPERATURE IN THE AIR BUBBLE OR CAVITY UNDER COMPRESSION WHEN SUCH HIGH TEMPERATURE CAUSES SURROUNDING NM LIQUID TO DECOMPOSE EXPLOSIVELY (I.E., INCLUDE CHEMICAL KINETICS OF NM AS AN EXPLOSIVE LIQUID).**
- (C) ANALYZE COMPRESSION OF ULLAGE IN U-TUBE TESTER. TREAT BOTH CASES, CONCENTRATED ULLAGE AND "FROTH" ULLAGE, BY METHODS OF CASE 3(B) WITH NM AS WORKING FLUID.**

- 4. PERFORM LABORATORY EXPERIMENTS WITH A U-TUBE TO TEST DIAGNOSTICALLY THE VALIDITY OF COMPUTER PREDICTIONS OF 3(C). (MEASURE PRESSURE AND TEMPERATURE OF COMPRESSED ULLAGE VS. TIME AND NOTE GO/NO-GO EXPLOSIONS, WITH VARIOUS CONDITIONS AND VARIOUS MODIFICATIONS OF END CLOSURES.)**

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